THE ANNALS OF “DUNAREA DE JOS” UNIVERSITY OF GALATI
FASCICLE IX. METALLURGY AND MATERIALS SCIENCE
N°. 2 - 2015, ISSN 1453 – 083X

THE STRUCTURAL DESIGN IMPROVEMENT OF A TWIN-HULL SHIP

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ABSTRACT

The paper is focused on the strength analysis of the structure of twin-hull ships, particularly a passenger catamaran. Catamarans have some advantages against conventional monohulls: larger deck area and cargo volume, better transverse stability and, in general, improved behavior in waves. But due to the need of large open spaces, for passenger / car ferry ships and having as major restriction the structure weight, one of the problems which arise during the designing of the catamaran structure is the determination of the effectiveness of deck structure. The Finite Element Method was used for examining the behavior of different deck structure designs in order to determine the solution which meets better designing criteria regarding allowable stress and deformations and total weight. The results of this analysis show that, making a proper structural analysis and using lightweight materials, important gains for ship owners and for environment protection can be achieved.

KEYWORDS: catamarans, deck structures, FEM analysis, lightweight materials

1. Introduction

This study is based on a new concept of inland navigation catamaran for 150 passengers, having 28.5 m length, 7.8 m beam, 1 m maximum hull draft and a maximum speed of 25 km/h. Considering the small draft and relatively high speed, the total light ship weight must remain as low as possible so the material used for construction of hulls, main deck and superstructure deck is aluminium or glass reinforced plastics (GRP).

The craft has a closed salon for passengers on the main deck and an open salon on the upper deck, which adds significant load on the upper deck structure.

In addition, this particular design meets the owner’s request for availability of different deck arrangements without any hull structure modifications.

Consequently, the number of pillars or other similar supporting structures was reduced to minimum or even none, in order to ensure maximum flexibility in deck arrangements, thus increasing the span of primary supporting members.

In this research, were analyzed different structure solutions for the upper deck, in order to meet, as far as practicable, the above designing restriction and other criteria, presented later.

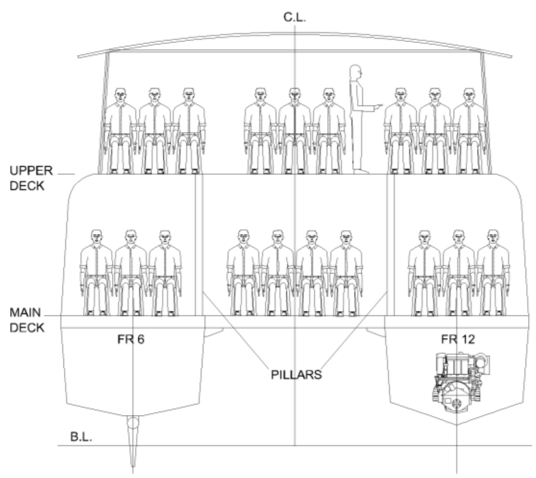

Fig. 1. *Ship transverse section*

2. Designing criteria and restrictions

In order to make a qualitative assessment of different structure designs, several designing criteria and also some objective restrictions were considered.

Designing criteria:

i) **Permissible stress** was considered for Aluminium Alloy 6005A-T6 as follows:

- primary stiffeners

σ_{locam}	τ_{locam}	σ_{VM}
76[N/mm^2]	54[N/mm^2]	86[N/mm^2]

- ordinay stiffeners

σ_{locam}	τ_{locam}
70[N/mm^2]	49[N/mm^2]

σ_{locam} – local permissible bending stress
τ_{locam} – local permissible shear stress
σ_{VM} – allowable equivalent stress

In order to reduce the weight, one aim was to avoid the oversizing of structure elements. Therefore, the geometric characteristics of primary and ordinary stiffeners were varied so to achieve stresses as close as possible to the permissible values, considering nevertheless a safety margin of 80% from the above mentioned values.

ii) The maximum allowable **deflection of the deck structure = 8 mm** was considered L/500, where L was taken as spacing between the transverse primary supporting members (maximum distance of 4 m). This limit of deflection is related to the on board people's well-being and is usually met in civil construction regulations.

iii) The maximum **deflection of windows framing = 5 mm** was considered not to exceed 1/175 of the glass smaller edge length (windows dimensions 2 m x 1 m), according to the United States building regulations (IBC 2006 Section 2403.3) as to ensure the integrity of the windows.

Designing restrictions:

i) The **weight** of the structure was optimized, as a general desideratum in ship building and especially for this catamaran with relatively small displacement (abt. 60 t) and shallow draft (abt. 1 m). In this regard, taking as example 1 t of weight reduction, several advantages can be gained for the project:

- more passengers on board 1 t = 10 average people with their luggage;
- more fuel oil and/or other stores on board, meaning greater flexibility in operation;
- less hull resistance because of draft reduction.

ii) **Ventilation ducts** required for the 150 people salon need a minimum height of 0.1 m clearance in order to ensure a good distribution of air and a reduced level of noise. In consequence, the upper deck stiffeners had either to allow such large cutouts for the passage of ventilation or to have minimum overall height so as to permit the installation of the ventilation duct underneath (Figure 2).

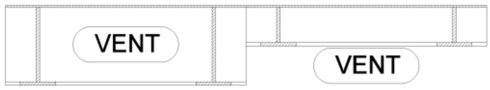

***Fig. 2.** Installation of ventilation ducts*

iii) **Structure arrangement** was another restriction, considering the owner's request to have minimum / none intermediate supporting members, at the level of main and upper decks. In this way it will be possible to rearrange the spaces, for example from a hidrobus / economy type for 100/150 passengers to a pleasure / business type for 60 passengers (Figure 3).

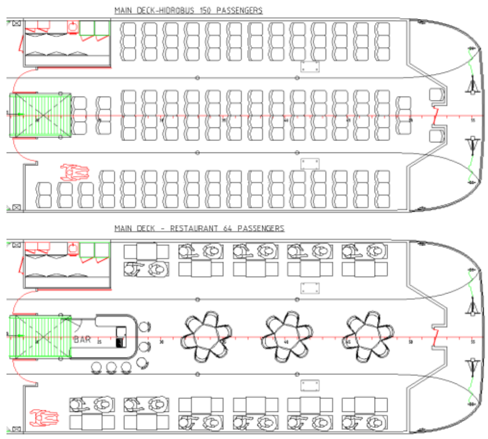

***Fig. 3.** Deck arrangement*

3. Assumptions and methods

In the structural analysis developed further, the following simplifying assumption was considered: the main deck (strength deck) of the catamaran is rigid and the transverse bulkheads enclosing the aft and fore ends of the upper deck structure are also rigid.

Boundary condition (Figure 4):

- fixed displacement and fixed rotation constraints at the level of the main deck (Ux, Uy, Uz, Rx, Ry, Rz);
- fixed displacement and fixed rotation constraints at transverse sections limiting de model in longitudinal direction (Ux, Uy, Uz, Rx, Rz).

Design loads:

- lateral pressure on the sides of the superstructure p_s = 2.3 kN/m^2, according to "NR217-Rules for Inland Navigation Vessels – PartB – Ch. 6, Sec 4";

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- pressure due to the load carried on deck p_d = 5 kN/m^2, according to "NR217-Rules for Inland Navigation Vessels – PartB – Ch. 6, Sec 4";
- weight of structure above the upper deck abt. 1 kN force at every supporting pillar.

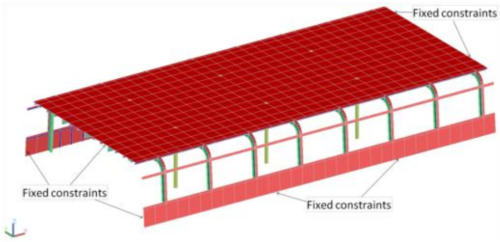

Fig. 4. *Boundary conditions*

The structural analysis was performed with Finite Element Method, using SHELL 3T elements, average size 0.05 m, COSMOS software and beam elements, NAUTICUS 3D-Beam software.

4. Analysis of different structure designs

The research started from a typical structure design, having primary supporting members disposed transversely at every 2 m and ordinary stiffeners spaced transversely and longitudinally at every 0.5 m. Based on "BV Rules for the Classification of Inland Navigation Vessels" some minimum net thicknesses were calculated for deck plating, web plating of ordinary and primary stiffeners.

Furthermore, this typical structure was optimized, considering the equal strength principle, aiming at lightening those elements with low stress and/or deflection.

Finally, a transverse arch structure was investigated aiming at reducing even more the total weight of the structure.

4.1. Typical structure

In Figure 5 below are shown the elements that form the structure:

- shell plates of 5 mm;
- primary supporting members web of 220 x 8 mm and flange of 100 x 8 mm;
- ordinary stiffeners web of 100 x 6 mm and flange of 100 x 8 mm;
- side bulkheads ordinary stiffeners face plate 70 x 6 mm;
- pillars of ϕ 130 x 10 mm.

The results showed the following situation:

- the maximum von Mises stress of 38 N/mm^2 (well below the limit of 86 N/mm^2) was reached in primary supporting members as shown in Figure 6;
- deck deflection of 4 mm, in the areas shown in Figure 7.

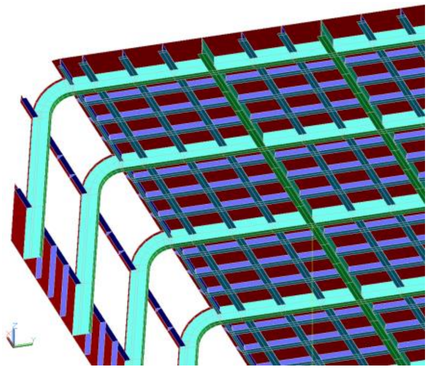

Fig. 5. *Typical structure details*

Total weight	Max. von Mises stress	Max. displacement
[t]	[N/mm^2]	[mm]
4.187	37.7	4.2

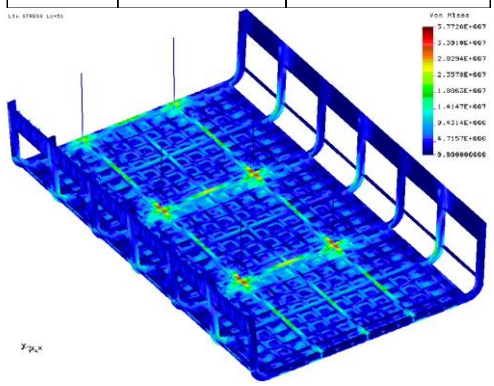

Fig. 6. *Typical structure - von Mises stress*

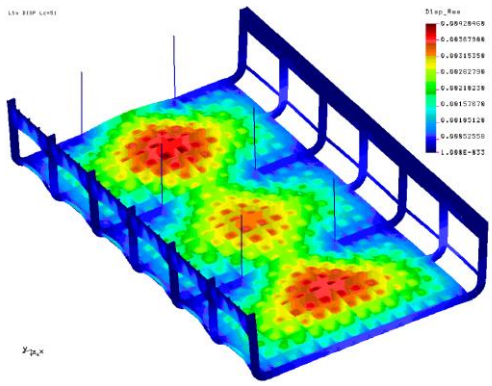

Fig. 7. *Typical structure - displacement*

4.2. Optimized typical structure

Based on the above results, some improvements are possible:

i) reducing and even eliminating the ordinary stiffener flanges of 100 x 8 mm, due to low stress level. The weight reduction was about 0.6 t (14% from the initial weight).

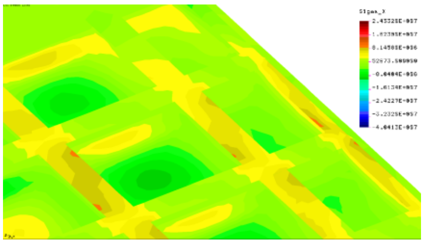

Fig. 8. *Typical structure – ordinary stiffener flange stress*

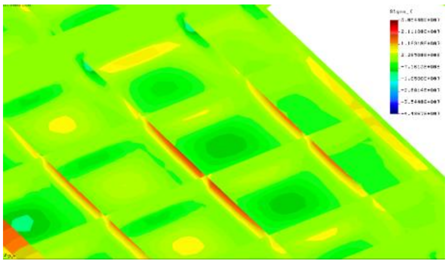

Fig. 9. *Optimized typical structure – ordinary stiffener flange stress*

ii) reducing the section area of vertical primary supporting members, due to the low stress level. The weight reduction obtained was about 0.175 t (4% from the initial weight).

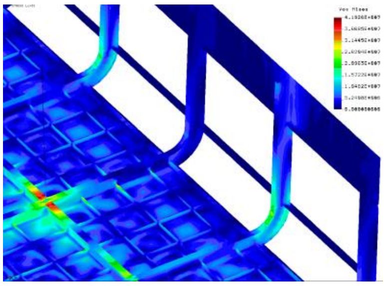

Fig. 10. *Typical structure – von Misses stress in primary vertical members*

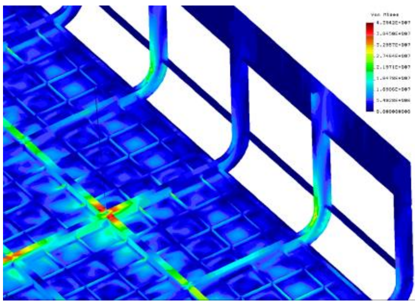

Fig. 11. *Optimized typical structure – von Misses stress in primary vertical members*

Total weight	Max. von Mises stress	Max. displacement
[t]	[N/mm^2]	[mm]
3.412	≈40	≈4

Conclusion: The total weight of the initial structure was reduced by 18%.

4.3. Transverse arch structure

Aiming at reducing the number of pillars and at the same time at keeping deck deflection below limits, a beam model was used to evaluate the efficiency of a transverse arch frame solution.

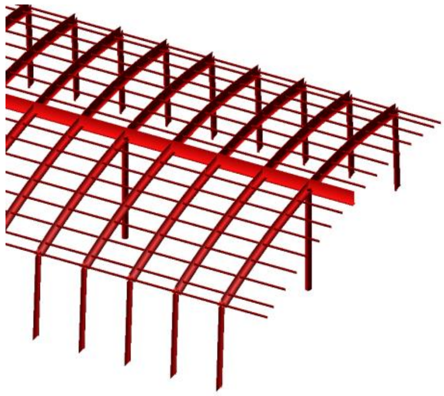

Fig. 12. *3D Beam model – arch structure*

In Figure 12 below are shown the elements that form the structure:

- arch transverse beam web of 200 x 10 mm;
- central longitudinal stiffeners web of 300 x 8 mm and flange of 100 x 8 mm;
- longitudinal ordinary stiffeners flat plate of 50 x 5 mm;
- side stiffeners web of 200 x 6 mm and flange of 50 x 5 mm;
- only one line of pillars of ϕ 130 x 10 mm.

The results showed the following situation:

Total weight	Max. von Mises stress	Max. displacement
[t]	[N/mm^2]	[mm]
3.820	45	5.6

Conclusion: The total weight increased by 12% than the optimized typical structure presented above but the deflection was similar.

By comparison, the same structure, but having straight transverse stiffeners, showed significantly higher deflection:

- the maximum von Mises stress of 69 N/mm^2;
- the maximum deck deflection of 8.2 mm.

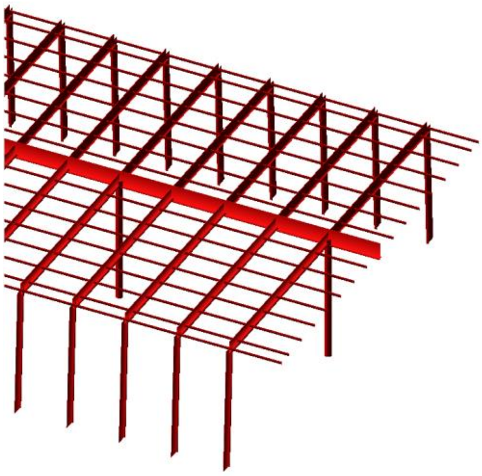

Fig. 13. *3D Beam model – straight transverse structure*

5. Conclusions

This research underlined two aspects:

i) the weight of a ship structure can be considerably decreased, from the initial design based on "Rules" dimensioning, using a FEM calculation;

ii) a classical structure solution, such as arch design, can be integrated in a ship structure in order to reduce the number of intermediate supporting members.

Acknowledgement

The present research has been supported by Ship Design Group Galati.

References

[1]. ***, *NR217 - Rules for Inland Navigation Vessels*, November Edition 2014.

[2]. ***, *2008 New York City Building Code*, (IBC 2006 Section 2403.3).

[3]. ***, COSMOS software.

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